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# NUTRIENT BALANCES OF WETLAND RICE FIELDS FOR THE SEMARANG DISTRICT (INDONESIA)

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## ABSTRACT

Data from 1978 to 2003 were analysed to evaluate the history of rice yields, rice producing area and total rice production for the Semarang District of Indonesia. The data were grouped according to the five-year development plans executed in Indonesia, called PELITA (*Pembangunan Lima Tahun*). Nitrogen, phosphorus and potassium balances of the wetland rice fields were assessed for the period 1999-2003. The highest average rice yield, about 5.10 t $ha^{-1}$, was reached during the PELITA V and the economic crisis era. In general, the N, P, and K balances were found to be negative, which points towards nutrient mining from the rice fields. When a high production level is targeted, nutrient mining can only be avoided by recycling rice straw and applying fertilisers at high rates.

***Keywords*:** nutrient balance, wetland, rice, district level, nitrogen, phosphorus, potassium

# INTRODUCTION

Up to now, Jawa Tengah or the Central Java Province is one of the main national Indonesian rice producers. Improving the rice yield is currently one of the most important targets in the food sector. In 2002, the rice yield reached 5.14 t $ha^{-1}$, and increased about 2.41 % compared to the previous year. The total rice production reached 8.50 million tons. Almost 97 % of the total rice production in this province comes from wetland rice cultivation (BPS, 2003a). The increasing rice yields could however lead to nutrient mining of the rice fields on the long term and thus threatens the sustainability of the agricultural system. We therefore aimed to assess the N, P, and K balances of wetland rice fields in this Indonesian region, provided that different inorganic and organic fertiliser application rates could have been applied. Moreover, a better understanding of the evolution of rice yields and insights in the strategic implementation to reach the rice production targets are essential to refine wetland rice management and make it more profitable and sustainable with less negative impacts on the environment. We therefore also discussed the history of rice yields, producing area, and total rice production between 1978 and 2003.

Nutrient balances can be developed on different scales and for different purposes (Hashim *et al.,* 1998; Santoso, *et al.,* 1995; Sheldrick *et al.,* 2003; Smaling *et al.,* 1993; Stoorvogel *et al.,* 1993; Sukristiyonubowo *et al.,* 2004 and 2003; Syers, 1996; Van den Bosch *et al.,* 1998a; 1998b). In the current paper, we constructed the nutrient balances for the rice fields on a district level. Among the rice growing centres in the Central Java Province province, the Semarang District was selected as study area as agriculture activities are still dominant in this district, although the industrialisation is also extending rapidly. Moreover, Keji Village, where field experiments were carried out which provided part of the data, is situated in this district.

## MATERIALS AND METHODS

### *Study area*

The Semarang District is one of the twenty-nine districts and six municipalities of the Central Java Province. Administratively, it is divided into 17 sub districts with a total surface area of about 95 021 ha or about 2.92 % of the total province area (BPS, 2002).

The district stretches out from 110° 14' 54.75" to 110° 39' 3" South Latitude and from 7° 3' 57" to 7° 30' 00" East Longitude. The area is predominantly mountainous consisting mainly of hills, with steep and very steep slopes (8 to more than 55 %), occupying about 55 %, and flat to gentle slopes (0 to less than 8 %) representing 45 % of the area. The elevation varies from 318 to 1,450 m above sea level.

The climate is characterised by two distinct seasons, a wet and a dry period. The wet or rainy season normally occurs from November to April, with a peak precipitation in January. The dry period extends from May to October, with the driest month in August. According to ten years climatic data, the average annual precipitation is approximately 2 402 mm, ranging from 1 924 to 3 196 mm, with the highest annual rainfall in 1998 (Figure 1).

Figure 1.

Approximately 26.12 % or 24,823 ha of the lands are granted to wetland rice (*sawah*) production. Around 15,764 ha can be planted two times a year. According to the irrigation network system constructed in the field, the paddy fields can be classified into rain-fed irrigation (6,017 ha), simple irrigation systems (8,910 ha), half (4,004 ha) and fully (5,525 ha) regulated technical irrigation systems. The latter produce more rice.

Agriculture is important for the economic development of the Semarang District. The importance of rice is not only expressed in terms of staple food, but also in generating on-farm income and creating on-farm occupation. In 2000, about 266,000 persons worked in the agricultural sector as farmers, farm workers, and rice traders, representing a four times higher employment compared to the industrial sectors (BPS, 2000).

In 2002, the number of inhabitants increased about 7 % compared to 1998. Consequently, land demands for housing, industries, and infrastructural development also enhanced and rice fields have been sacrificed. As a result, land conversion from agricultural to non agricultural purposes constitutes an important challenge for sustaining the rice production and food security in this district.

***Rice production from 1978 to 2003***

Data on the history of rice yields, producing area, and total rice production between 1978 and 2003 were obtained mainly from the Statistic Agency of the Semarang District (BPS, Biro Pusat Statistik). As multiple crises struck Indonesia, the period of 1978 to 2003 represents three distinct situations, including the New Order Government (1978-1993), the New Order Government with the economic crisis period (1994-1998), and the Reform Order Government with the economic recovery period, from 1999 to 2003 (National Information Agency, 2003). During the New Order Government, a national development plan was designed for 25 years, from 1969 to 1993, called the First Long-term Development Programme. This was executed through Five-Year Development Plans called PELITA (*Pembangunan Lima Tahun*). The data were grouped and analysed in accordance with this plan. The mean producing area of every PELITA was considered as the unit area for the district level analysis.

***Construction of the nutrient balances***

The nutrient balances were computed according to the differences between estimated nutrient inputs and nutrient outputs for the economic recovery period (with available rice production data, i.e. from 1999 to 2003). The necessary data were obtained mainly from the Statistic Agency of the Semarang District (BPS, Biro Pusat Statistik), and also from the Food Crop Services Department, own field experiments and field monitoring, including interviews with the farmers.

Assessment of nutrient balances was done for rice farming in terraced paddy field systems. The terraces were flat, different in size, and arranged descending to the river. Nutrients coming into the rice fields were considered as input, whereas nutrients removed from the fields were classified as output. Nutrient originating from inorganic fertiliser (IN-1), organic fertiliser (IN-2), irrigation (IN-3) and rainfall (IN-4) were grouped as input. Losses through rice grains (OUT-1), rice straw (OUT-2) and erosion (OUT-3) were categorised as outputs.

Four treatments were applied, including (1) Conventional Farmer Practices (CFP), (2) Conventional Farmer Practices + Rice Straw (CFP + RS), (3) Improved Technology (IT), and (4) Improved Technology + Rice Straw (IT + RS). They were arranged in the Randomised Complete Block Design (RCBD) and replicated three times. In the CFP treatments, only 50 kg $ha^{-1}$ $season^{-1}$ of urea was applied. In the IT treatments, fertiliser application rates of 100 kg $ha^{-1}$ $season^{-1}$ each of urea, TSP, and KCl were applied, corresponding to the recommendation fertiliser application rates for rice provided by the Food Institute at District Level. These rates were introduced since the cropping season 2000-01. In the RS treatments, the amount of rice straw recycled was 33 % of the previous rice straw production. The recycled rice straw was distributed on the field prior to the first land ploughing and incorporated during ploughing. The recycling of 33 % of rice straw production was obtained from the results of previous study (see Sukristiyonubowo et al., 2003) and accepted by farmers during the meeting. Twelve farmers were involved in this study, corresponding to the four treatments and three replicates.

Data on N, P and K were collected from twelve participating farmers (four treatments and three replicates). They were subsequently extrapolated to a hectare basis (kg $ha^{-1}$ $season^{-1}$). To quantify input, collected data included concentration of nutrients in inorganic fertiliser, rate of fertiliser application, amount of returned rice straw used as organic fertiliser, irrigation water supply, nutrient concentrations in irrigation waters, precipitation, and nutrient concentration in rainfall. The output parameters were rice grain yields, rice straw production, nutrient concentrations in rice grain and rice straw, and soil erosion. These data were measured during the wet season 2003-04 (WS 2003-04) and the dry season 2004 (DS 2004).

The rice residues were not taken into account either as an input nor an output in this balance assessment, as practically, they always remain in the field.

Nitrogen fixation, especially by Azolla sp. may contribute significant to N-input. However, it was not considered as an input, as practically, farmers have not grown Azolla sp. in the rice fields for more than 15 years.

Field monitoring and interviews were simultaneously done in all sub districts under the Semarang District. Field monitoring and opened interviews (without questionnaires) were directly carried out in the field. The mainly aimed were to gather data about rice straw management and the fertilisers' application rates. The farmers met in the fields were the target to be interviewed. Five farmers were seen for each sub district.

Losses through $NH_3$-volatilisation and denitrification were not taken into account. These outputs may be considered significant as reported in many studies (Cho *et al.,* 2000; Chowdary *et al.,* 2006; Fan *et al.,* 2006; Ghost and Bhat, 1998; Hayashi *et al.,* 2006; Manolov *et al.,* 2003; Xing and Zhu, 2000). However, due to some practical restrictions, we could not collect data to estimate them for the district level. In that way, the N outputs are somewhat underestimated. Moreover, erosion could be neglected as an output as another study already indicated this (Sukristiyonubowo, 2007).

As IN-1 could not be assessed exactly, several hypothetic values were used. They were calculated based on commonly used (i.e. control) and recommended fertilisation rates and the average producing area, which was known exactly. The used fertiliser application rates ranged from 50 to 250 kg of urea, 0 to 200 kg of TSP and 0 to 150 kg of KCl and were classified into control, low, medium and high rates. The low fertilisation rate included the application of 100 kg urea, 100 kg TSP, and 50 kg KCl $ha^{-1}$ $season^{-1}$, the medium rate 175 kg urea, 150 kg TSP, and 100 kg KCl $ha^{-1}$ $season^{-1}$ and the high rate 250 kg urea, 200 kg TSP, and 150 kg KCl $ha^{-1}$ $season^{-1}$. The fertiliser application rates recommended by the Food Crop Services for the Semarang District range between 100 and 250 kg $ha^{-1}$ $season^{-1}$ for urea, between 100 and 200 kg $ha^{-1}$ $season^{-1}$ for TSP, and it is 100 kg $ha^{-1}$ $season^{-1}$ for KCl. Instead of these "recommended rates", only 50 kg of urea $ha^{-1}$ $season^{-1}$ is often applied by the farmer due to financing difficulties. This "farmer rate" was therefore added as a control. The farmers often recycle 33 % of the rice straw produced in the previous growing season and use the rest to feed their cattle. This amount was used in combination with the nutrient content of the straw as an estimation of IN-2. The rice straw production at the district level was computed based on its relation with rice grain yields and rice residues, as measured in field experiments (Sukristiyonubowo, 2007; Sukristiyonubowo *et al.,* 2004; 2003). The nutrient content was estimated taking into account the average nutrient contents in rice straw of the WS 2001-02, DS 2002, WS 2002-03, DS 2003, WS 2003-04 and DS 2004. These averages ($\pm$ standard deviations) were 1.05 $\pm$ 0.10 % N, 0.10 $\pm$ 0.02 % P, and 2.05 $\pm$ 0.19 % K. As the use of rice straw however differs among farmers, the nutrient balances were also constructed and evaluated without rice straw recycling. IN-3 was calculated by multiplying the nutrients deposited by irrigation water per surface area unit, as measured in the field experiments, with the total producing area at district level (Sukristiyonubowo, 2007). IN-4 was estimated by multiplying the annual rainfall volume with the average nutrient concentration in the rainwater.

OUT-1 was calculated by multiplying the rice production with the average nutrient concentrations measured during the field experiments, between the wet season (WS) 2001-02 and dry season (DS) 2004. The average (± standard deviations) nutrient concentrations in grains from WS 2001-02, DS 2002, WS 2002-03, DS 2003, WS 2003-04, and DS 2004 were 1.46 ± 0.22 % N, 0.20 ± 0.05 % P, and 0.30 ± 0.04 % K (Sukristiyonubowo *et al.,* 2004; 2003). OUT-2 was computed by multiplying the rice straw production with the average nutrient concentration in the straw. The rice straw production for the district level was estimated from its relation with rice grain and residue yields, measured at field level between the WS 2001-02 and DS 2004. The average nutrient concentrations in the rice straw were compiled from the field experiments between the WS 2001-02 and DS 2004.

## RESULTS AND DISCUSSION

### *Rice production from 1978 to 2003*

A better understanding of rice yields during the different PELITA periods and insights in the strategic implementation to reach the rice production target set in every PELITA are essential to refine wetland rice management and make it more profitable and sustainable with less negative impacts on the environment. The rice yield, producing area, and total rice production between 1978 and 2003 are therefore given for the Semarang District in Table 1. The data were evaluated for every period of the development plan, compared to 1978. The highest improvement of rice yield, about 48 %, was found in the PELITA V and the Economic crisis era. The highest producing area was observed during the PELITA IV (14 % higher compared to 1978), whereas the total production was highest during PELITA V (67 %

higher compared to 1978). The change of rice varieties from local to high yielding and the development of irrigation networks greatly contributed to the increase of production intensity, which led to a higher total rice production.

Table 1.

In the PELITA III (from 1979 to 1983), rice yield, producing area, and total rice production were 3.73 t $ha^{-1}$, 28,753 ha $yr^{-1}$ $district^{-1}$, and 107,625 t $yr^{-1}$ $district^{-1}$, showing an increase of 8 %, 2 %, and 10 %, respectively, compared to 1978. Planting new high yielding varieties (HYV) and applying the recommended fertilising rates successfully increased the rice yields and the total rice production. The introduction of HYV focused on the improvement of quantitative and qualitative aspects of rice production. The shorter live cycle of HYV compared to local varieties increased the planting intensity.

In the PELITA IV (from 1984 to 1988), the improvements continued. The grain yield, producing area, and total production increased by 24 %, 12 %, and 39 %, compared to the previous PELITA. Moreover, Indonesia has been recognised to be self-sufficient in rice during this period. The end of PELITA IV was marked by the highest total production, 180,146 t $yr^{-1}$ $district^{-1}$, and the largest producing area, 35,057 ha $yr^{-1}$ $district^{-1}$. This could be attributed to successfully planting new HYV and the application of recommended fertiliser rates in all major producing areas, besides other efforts, as providing credit, developing irrigation networks, and improving farmer's knowledge through training and farmer group meetings, as well as daily TV programmes for farmers at national and regional stations.

During the PELITA V (from 1989 to 1993), average rice yields reached 5.10 t $ha^{-1}$, varying between 4.64 and 5.42 t $ha^{-1}$. This coincided with the highest average rice yield for this district and the highest total production. Compared to the PELITA IV, the rice yield and total rice production increased about 10 % and 8 %, respectively. Moreover, in 1991, the rice yield and total production decreased about 14 % and 13 %, respectively, compared to the rice yield and total production in 1990. This was attributed to a drought period, diseases, and pest attacks.

After the First Long-term Development Programme, the Indonesian Government has incessantly started with a Second Long-term Development Programme to continue rising economic goals and improving the standard of living. However, this programme was not successful because of political, social and economical crises. During the economic crisis (1994 – 1998), the average rice yield remained about 5.10 t $ha^{-1}$ as during the PELITA V, indicating that the rice yield in this district was generally not directly affected by the crises. However, the producing area and total production decreased about 1 %. During this period, especially from 1995 to 1997, the recommended fertilisers' rates were not well applied. The price of fertilisers including urea, TSP and KCl were getting increase and sometimes they were not available in the market when they were needed. To anticipate such conditions, the farmers added about one to three tons $ha^{-1}$ cattle manure (compost) and some of them also recycled the rice straw of about 20% of the previous straw production. The farmers also realised that the amount of organic manure should be improved to get better yield. We, therefore, suggested that the residual fertilisers combined with organic manure and or retuned rice straw may sustain high rice yield. It was important to be noted that fertilisers' application rates given by the farmers, from 1973 to 1994, were considered high and planting high yielding rice varieties have already been adapted. According to the farmers met in the fields about 300 kg urea, 100 kg TSP and 100 kg KCl $ha^{-1}$ $season^{-1}$ were applied. Hence, addition of cattle manure and rice straw may recapitalize P in the soil and refresh the soil system, resulting in improving rice yield.

During the Economic recovery period (from 1999 to 2003), the rice yield and total rice production varied between 4.78 and 5.28 t $ha^{-1}$ and between 146,021 and 173,314 t $yr^{-1}$ $district^{-1}$, respectively. These variations were mainly attributed to differences in fertiliser application rates, as the farmers were facing financial difficulties as well the problem of fertilisers' price. Supplementary efforts, such as providing credit, improving farmer's knowledge through training and farmer group meetings, as well as daily TV programmes for farmers at national and regional stations (as in the period of 1978 to 1993) were not well implemented.

***Nutrient Balances 1999-2003***

The N, P, and K balances constructed with all of the hypothetic fertilisation rates are given in Table 2. For the control fertiliser application rate (farmer rate), the most negative N, P, and K balances were observed. This means that conventional farmer practices using only 50 kg of urea $ha^{-1}$ $season^{-1}$ as fertiliser are not sustainable and not longer recommended.

Even when 33 % of the rice straw produced in the previous growing season was reused as fertiliser, the N balances could only have been positive when N fertilisers would have been applied at the highest recommended rates, which was undoubtedly not the case in the whole district. Moreover, the N output is also underestimated as denitrification and volatilisation could not be taken into account. Nitrogen mining from the rice fields is thus expected to have occurred.

As the P content of rice straw is low and the output by grains is very high, the P balance is mainly influenced by the application of P fertiliser. For all hypothetic recommended fertiliser application rates, positive P balances were observed. However, P losses seem to occur when no P fertiliser is used (i.e. in the control). To counteract the P removal, the application of a small amount of P (e.g. 100 kg of TSP $ha^{-1}$ $season^{-1}$) may be recommended.

Negative K balances were observed for all hypothetic inorganic fertiliser application rates. Extra K input by recycling 33 % of the rice straw produced in the previous growing season significantly reduces the deficits, but cannot compensate the K removal by harvest completely. Hence, K fertiliser application should be combined with rice straw recycling to avoid K mining from the rice fields. Recycling larger parts of the rice straw might also be an option, but this is expected to conflict with the use of rice straw for feeding the cattle.

Due to the limited availability of data, the nutrient balances could only be roughly estimated. They already clearly point towards the occurrence of nutrient mining, but should be refined in the future. An effect of applying different fertilisation rates on the nutrient output was e.g. expected, but could not be considered.

## CONCLUSION

Between 1978 and 2003, the rice yields in the Semarang District ranged from 3.45 to 5.10 t $ha^{-1}$. The rice yield was highest during the economic crisis, showing that applying mineral fertilisers and organic manure (compost and returned rice straw) can keep high rice productivity; therefore, organic fertilisers should be included in managing rice field. Constructed nutrient balances clearly point towards the occurrence of nutrient mining. The application of small amounts of P fertiliser and large amounts of N fertiliser should be recommended to avoid nutrient P and N mining from the rice fields, whereas increased rice straw recycling in combination with the use of K fertilisers is suggested to avoid K mining.

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TABLES

Table 1. Rice yield, producing area, and total rice production in the Semarang District (Indonesia)

| Period-Development Plan | Year | Rice Yield (t ha$^{-1}$) | Producing Area (ha yr$^{-1}$ district$^{-1}$) | Production (t yr$^{-1}$ district$^{-1}$) |
|---|---|---|---|---|
| New Order Government: | | | | |
| PELITA II | 1978 | 3.45 | 28,215 | 97,364 |
| | | | | |
| PELITA III | 1979 | 3.18 | 24,244 | 77,462 |
| | 1980 | 3.56 | 29,284 | 104,280 |
| | 1981 | 3.61 | 32,217 | 116,092 |
| | 1982 | 3.91 | 29,356 | 114,593 |
| | 1983 | 4.39 | 28,664 | 125,698 |
| *Mean ± stdev* | | *3.73 ± 0.45* | *28,753 ± 2,872* | *107,625 ± 18,492* |
| PELITA IV | 1984 | 4.76 | 31,199 | 148,620 |
| | 1985 | 4.36 | 28,435 | 123,979 |
| | 1986 | 4.61 | 34,692 | 159,817 |
| | 1987 | 4.28 | 31,865 | 136,446 |
| | 1988 | 5.14 | 35,057 | 180,146 |
| *Mean ± stdev* | | *4.63 ± 0.35* | *32,250 ± 2,723* | *149,802 ± 21,608* |
| PELITA V | 1989 | 5.34 | 32,121 | 172,138 |
| | 1990 | 5.42 | 30,702 | 166,305 |
| | 1991 | 4.64 | 32,148 | 145,134 |
| | 1992 | 5.14 | 32,497 | 167,124 |
| | 1993 | 4.95 | 33,140 | 164,040 |
| *Mean ± stdev* | | *5.10 ± 0.31* | *32,122 ± 894* | *162,948 ± 10,389* |
| The Economic crisis: | 1994 | 4.66 | 29,204 | 136,091 |
| | 1995 | 5.36 | 31,986 | 171,340 |
| | 1996 | 5.09 | 32,693 | 166,382 |
| | 1997 | 5.33 | 31,338 | 159,536 |
| | 1998 | 5.08 | 34,541 | 175,606 |
| *Mean ± stdev* | | *5.10 ± 0.28* | *31,952 ± 1,948* | *161,791 ± 15,562* |
| The Economic recovery: | 1999 | 4.78 | 32,332 | 154,482 |
| | 2000 | 5.28 | 32,804 | 173,314 |
| | 2001 | 4.93 | 29,624 | 146,021 |
| | 2002 | 5.19 | 33,062 | 171,694 |
| | 2003 | 4.82 | 30,285 | 146,047 |
| *Mean ± stdev* | | *5.00 ± 0.22* | *31,621 ± 1,562* | *158,312 ± 13,419* |

Table 2. The nutrient balances of wetland rice fields with ( + RS ) and without ( - RS ) returning rice straw for the Semarang District (Indonesia) in the period 1999-2003

| | Nutrient Balance (t $yr^{-1}$ $district^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | High | | Medium | | Low | | Control | |
| | + RS | - RS | + RS | - RS | + RS | - RS | + RS | - RS |
| **N:** | | | | | | | | |
| Total Input | 4,893 | 4,155 | 3,826 | 3,088 | 2,659 | 2,021 | 2,047 | 1,309 |
| Total Output | 4,476 | 4,476 | 4,476 | 4,476 | 4,476 | 4,476 | 4,476 | 4,476 |
| Balance | + 417 | - 321 | - 650 | - 1,388 | - 1,817 | - 2,455 | - 2,429 | - 3,167 |
| **P:** | | | | | | | | |
| Total Input | 1,367 | 1,300 | 1,051 | 984 | 734 | 667 | 102 | 35 |
| Total Output | 505 | 505 | 505 | 505 | 505 | 505 | 505 | 505 |
| Balance | + 862 | + 795 | + 546 | + 479 | + 229 | + 162 | - 403 | - 470 |
| **K:** | | | | | | | | |
| Total Input | 4,193 | 2,756 | 3,403 | 1,986 | 2,613 | 1,176 | 1,822 | 385 |
| Total Output | 4,703 | 4,703 | 4,703 | 4,703 | 4,703 | 4,703 | 4,703 | 4,703 |
| Balance | - 510 | - 1,947 | - 1,300 | - 2,717 | - 2,090 | - 3,527 | - 2,881 | - 4,318 |

FIGURES

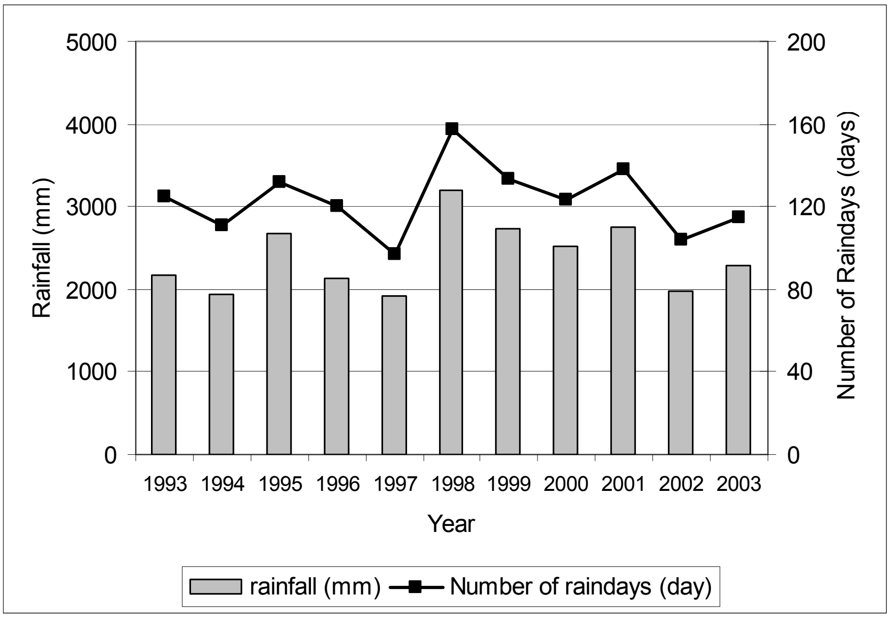


Figure 1. Annual rainfall and rain days during ten years, from 1993 to 2002, for the Semarang District (Indonesia)